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(19)(CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Ultrasonic Destruction of Microorganisms in Shipboard Fuel and Ballast Water Systems

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Notice: This application is as filed and may therefore contain an incomplete specification.

Ultrasonic Destruction Of Microorganisms In Shipboard Fuel And Ballast Water Systems

Abstract

A process and apparatus for the ultrasonic destruction of microbiological contamination of naval distillate fuel. The process involves subjecting contaminated fuel to ultrasonic vibration so as to cause cavitation within the liquid. The cavitation results in the destruction of microbial cells and mats of microbial colonies. The process is also applicable to other liquids such as potable and marine ballast waters.

Ultrasonic Destruction Of Microorganisms In Shipboard Fuel And Ballast Water Systems

Field of the Invention

The present invention relates to a method and apparatus for the control of microbial contaminants in liquids and, more particularly, to the destruction of such contaminants in shipboard fuels and ballast waters by the use of ultrasonic vibration.

Background of the Invention

Microbiological contamination of hydrocarbon fuels presents a variety of problems to the operators of naval vessels. Some of the organisms responsible for such contamination are fungi, yeast and bacteria.

In naval vessels, it is common for water to be found in on board fuel tanks. This water originates from various sources such as condensation from the fuel, water leakage into the fuel or from water taken on as ballast in the tanks. The presence of water in the fuel tank results in the proliferation of yeasts and fungi at the fuel/water interface where the microbial contaminants extract oxygen from the water and nutrients from the fuel layer. Some forms of these microorganisms produce water as a byproduct, thereby altering the environment of the fuel/water interface and allowing other microbial forms to flourish.

Various problems arise from the microbiological contamination of fuel including:

a) Mat-like or slimy deposits at the fuel/water interface;

b) Blockages of valves, pumps, filters and coalescers;

c) Reduction in interfacial tension resulting in the malfunction of water separating devices;

d) Accelerated corrosion of steel and aluminium;

e) Black stains on copper alloys or silver plated components;

f) Injector fouling; and

g) Probe fouling and incorrect volume measurement.

Some of these problems have previously been documented (R.D. Haggett and R.M. Morchat, *Intl. Biodeterioration & Biodegradation* **29** (1992) 87-99).

These consequences can be tolerated at minor levels of infection. However, as the microbial population flourishes, serious and costly failures are inevitable. Generally, contamination problems are only investigated when the failure or malfunction of equipment occurs. Any fuel tanks, and associated systems, found to contain such contaminants must be drained, cleaned, dried and inspected prior to being reused.

Completely sterile natural environments are rare and without strong chemical additives toxic to microbes, some level of contamination can always be expected. However, if the levels of this contamination can be kept below critical levels, their proliferation can be prevented and the damaging consequences avoided.

At present, the only means of controlling microbiological contamination in ship board fuel systems is to prevent water from accumulating in fuel tanks, which is extremely difficult and impractical, or to treat the contaminated fuel with biocidal agents. However, the use of such biocides presents environmental and health and safety concerns. Questions have arisen concerning the effect of biocide containing fuel on personnel working daily with fuel system components as well as personnel working in confined spaces where they may be exposed to vapours containing

the biocide. The environmental concern relates to the effect that such biocidal agents may have if introduced into already sensitive marine ecosystems. The selective nature of biocides presents a further problem in their usage. For example, while some biocides are effective against fungi they have little or no effect on bacteria. Further, while some biocides inhibit growth of pure microbial cultures, their effectiveness is drastically reduced when applied to mixtures of fungi, yeasts and bacteria.

The use of ultrasound as a germicidal agent has been investigated previously by G. Scherba et al (*Applied and Environmental Microbiology* 1991, 2079-2084) and H. Kinsloe et al (*J. Bacteriology* **68** (1954) 373-380). The literature on the treatment of microorganisms using ultrasonics is sparse; but all studies that have been carried out agree that it is an effective means of destroying microorganisms. A shipboard application of this technology is waste water treatment. This possibility was studied by the U.S. Navy Coastal Systems Station in 1976 (A.J. Ciesluk, "Acoustic Sterilization For Shipboard Waste Management", U.S. Navy Coastal Systems Station Technical Report, NCSC-TR-329-78). In this study, two commercial ultrasonic cleaners were used at two different power levels; however, it was concluded that the basin volumes of these cleaners were too large to lead to effective cell disruption. The literature does not describe the use of ultrasound to control microbial populations in fuel systems although the possibility has been proposed (E.C. Hill (1986), "Microbial Problems In Offshore Oil Industry" Proceedings of the International Conference, Inst. Petroleum Microbiology Committee, Aberdeen, U.K.).

Because of its inherent safety and relatively low power requirements compared to other physical control measures, ultrasound may represent the ideal solution to microbiological contamination of fuel systems. If the fuel and/or the water in the vicinity of the fuel/water interface is treated on an ongoing basis, the microbial populations can likely be kept below critical

levels. This would represent a more environmentally friendly and more effective control measure than the biocides currently in use.

Summary of the Invention

Accordingly, it is an object of the present invention to overcome the limitations of known fuel decontamination methods and provide a safe and effective process for the control of microbial populations in fuel systems. It is also an object of the present invention to provide a system and a process for the effective treatment of microbiologically contaminated ballast waters prior to disposal thereof. It is a further object of the invention to provide a process for disrupting the mats formed by microbial colonies and to improve the separation of water from a fuel.

Specifically, the present invention provides a process for neutralizing microbiological contamination of a liquid fuel comprising subjecting the fuel to ultrasonic vibrations at a predetermined vibration energy level and with a predetermined frequency, intensity and duration, in order to cause cavitation within the liquid and, thereby, to destroy the microbial contaminants.

In addition, the invention also provides an apparatus for the ultrasonic treatment of a microbiologically contaminated liquid comprising:

a treatment chamber containing an ultrasonic vibration generating means for subjecting ultrasonic vibrations on the liquid at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction;

wherein the contaminated liquid is passed through the chamber and is subjected to ultrasonic vibrations resulting in cavitation in the liquid and the destruction of microorganisms contained therein.

Brief Description of the Drawings

These and other features of the invention will become more apparent in the following detailed description in which reference is made to the appended drawings wherein:

Figure 1 is a schematic view of a first embodiment of the ultrasonic decontamination system;

Figure 1A is a cross sectional view of an ultrasonic horn chamber of Figure 1;

Figure 2 is a schematic view of a second embodiment of the ultrasonic decontamination system;

Figure 3 is a schematic view of a laboratory scale system for a first embodiment of the invention;

Figure 4 is a schematic view of a laboratory scale system for a second embodiment of the invention;

Figure 5 is a summary of the results of a static test using the ultrasonic horn;

Figure 6 is a summary of the results of a static test using the ultrasonic cleaner;

Figure 7 is a summary of the results of a flow test using the ultrasonic horn;

Figure 8 is a summary of the results of a flow test using the ultrasonic cleaner and;

Figure 9 is a schematic view of a third embodiment of the invention.

Detailed Description of the Preferred Embodiment

In Figures 1 and 1A, a first embodiment of the ultrasonic treatment system is illustrated generally at **10**. The system comprises a linear array of ultrasonic treatment chambers **12** each containing an ultrasonic horn, or probe **13**. The fuel containing microbial contaminants enters a manifold **14** at entry port **16**. The fuel is passed into the chambers **12** and under the horns **13**

where it is subjected to ultrasonic waves at a sufficient level to cause cavitation in the fluid which in turn leads to cell destruction of the contaminants. The fuel then enters a second collecting manifold **18** and exits the system.

Mechanical vibrations from the ultrasonic horn give rise to alternating compressions and rarefactions in the surrounding liquid. Upon rarefaction, vapour filled cavities are created in the liquid which are collapsed or imploded during compression. The localized stresses resulting from this cavitation process lead to the destruction of microbial cells.

Figure 2 illustrates a second embodiment of the invention wherein the system, indicated generally at **20**, consists of a water tank **22** having an array of transducers **24**. Within the water tank is a submerged coiled conduit **26** through which the fuel to be treated flows, entering at **28** and exiting at **30**. In this system, the transducers, **24**, mechanically generate vibrations of the desired level which are conducted by the water in the tank and, in turn, to the fuel within the conduit. The vibrations are generated at sufficient strength so as to result in cavitation within the fuel and, thereby, microbial cell destruction.

The factors affecting cavitation are frequency, power density, time of exposure, and the physical and chemical characteristics of the liquid that is being processed. Ultrasonic frequencies extend from about 20kHz up to the 1Mhz range. Power density is a function of the power of the transducer and the size of both the transducer and the container over which the sound waves are distributed. It is generally expressed in units of watts/cm^2, which refers to the surface area of the transducer.

The frequency of the ultrasonic wave influences the size and number of cavities created. The larger the cavities, the greater the force of implosion and, thus, the greater the effectiveness of cell disruption. Low frequencies cause a few large cavities which generate stronger shock waves. Higher ultrasonic frequencies require much greater power input to produce cavitation.

The cavities that are produced are generally smaller than at low frequencies. High frequencies produce a more directed beam of ultrasonic waves, which do not disperse well throughout the medium.

The high frequency systems that are used for medical imaging operate in the MHz range, with total transducer power in the range of a few watts. These systems do not produce cavitation since the energy threshold at which cavitation begins increases with frequency. The ideal frequencies for microorganism disruption are in the lower range of ultrasonic frequency (15 to 100 kHz). Frequencies higher than 20 kHz have generally been used in order to reduce the potential for damage to operator's hearing.

An important factor in ultrasonic disruption of microorganisms is the power density of the acoustic energy in the volume of material processed. Ultrasonic horns or probes, which concentrate the energy output over a small area, are commercially available for the destruction of microorganisms. The tip of the probe typically has an area of 1 cm^2. Such devices produce high energy density levels (100 to 1000 watts/cm^2). The intensity levels can be several orders of magnitude higher in the vicinity of these probe tips than the levels in common ultrasonic cleaners. In addition to the larger transducer surface area, ultrasonic cleaners typically dissipate the power over a relatively large basin volume. For cleaning applications, the effect of power level can be categorized as follows:

light cleaning:	1 - 2 watts/litre
medium cleaning:	6 - 10 watts/litre
heavy cleaning:	15-35 watts/litre

Effective disruption of microorganisms has been reported in the heavy cleaning range at 28 watts/litre only in combination with biocide additives. At higher power densities such as 3

watts/cm² at a distance of 1 cm from the probe, up to 90% disruption of *P. aeruginosa* was demonstrated using no chemical additives. *E. coli*, however, showed no intensity effect over the range of 1 to 3 watts/cm². A power input of 200 to 500 watts can disrupt over 70% of the microorganisms in a volume of 2 ml. Below these power levels the effectiveness was shown to drop off rapidly.

Power density is a function of the volume of liquid and the distance of the transducer from the liquid sample. As the volume of liquid is increased, the percentage of cell breakage decreases. Samples are often suspended in a water bath. Although it was expected that the destruction rate would be a minimum when the sample is placed at wave nodes, the effectiveness was simply reduced as the distance from the transducer was increased. A related variable is the depth or geometry of the container. This can be a factor especially if the vibrations are transmitted to the liquid through the container. The percentage of cell breakage was shown to be a quasi-sinusoidal function of the depth of the container, but the maxima and minima did not coincide with the predicted locations of the wave nodes.

The time of exposure can influence the effectiveness of ultrasonic destruction of microorganisms. The magnitude of the effect depends on the type of microorganism and can be affected by the power density. Although considerable scatter is seen in the data, differences were found between the time dependence of the kill rate at high and low intensities for *P. aeruginosa*. At the highest intensity of 3 watts/cm², the kill rate increased from about 70% to 85% as exposure time was increased from 1 to 32 minutes, but the exposure time effect was much greater at lower intensities. The time exposure effect was more consistent across power levels in other species and compared favourably with the lowest effects seen with *P. aeruginosa*.

The degree of cavitation produced by ultrasound is affected by the physical and chemical characteristics of the material being processed. An increase in viscosity increases the energy

density threshold required for cavitation. The temperature also affects the amount of cavitation. The intensity of the hydrodynamic shock waves increases as temperature is increased to 60°C and then declines. The decline may be due to an increased vapour pressure inside the cavities. The presence of solvents with high vapour pressure (e.g. ether, acetone) increases hydrostatic pressure above the liquid and decreases cavitation. An increase in the overall pressure of the system inhibits disruption. Changes in pH can also affect cavitation in some microorganisms although this effect was not observed for *P. aeruginosa*.

For non-fuel systems, it has been found that:

1. The power input (or energy density) has a dramatic effect on the efficiency of the system. As the energy density increases, the disruption rate increases;
2. As exposure time increases, the amount of microorganism disruption increases. In general, a logarithmic relation was found between the percentage of survivors and the exposure time;
3. As the temperature is increased, the rate of microorganism disruption is increased. Trials at just above 0°C experienced virtually no cell disruption. Trials were typically carried out between 15° and 50°C. The activity of the ultrasonic transducer itself increases the temperature to a plateau depending on the transducer, solution and container characteristics;
4. Lower frequencies are more effective in microorganism disruption since they promote cavitation with lower power levels and greater dispersion of energy. Frequencies around 20 kHz are most commonly used;
5. Young bacterial cultures (3 to 4 hour cultures) were most susceptible to ultrasonic disruption than older (18 to 24 hour) cultures;

6. Ultrasound combined with chemical control provides increased overall effectiveness;

7. The geometry of the container can have an effect by resonating with the sound waves;

8. Larger volumes dissipate the sound energy leading to lower disruption rates. Large volumes can also lead to "dead zones" of cavitation. This can be minimized by careful positioning of the transducer or by using multiple probes;

9. The pH of the solution can affect the ultrasonic destruction rate of some microorganisms;

10. Increased pressure and viscosity of the fluid reduces disruption effectiveness;

11. The disruption effectiveness depends on the type of microorganism. Rod shaped bacteria such as *P. aeruginosa* break very easily. Yeasts are next easiest to destroy followed by coccal forms of bacteria and chlorella. Spores and mould vegetative mycelium are most resistant. No difference was found in the susceptibility of gram positive and gram negative bacterial forms suggesting that the site of destruction may be the inner cytoplasmic membrane.

The most important factors leading to cavitation and, thus, to the successful destruction of microorganisms, are the power density and frequency. The power density is the number of watts provided by the system divided by the surface area of the transducer. It is also a function of the size and geometry of the container. Most of the literature does not provide the surface area

of the transducer; however, one reference (Scherba et. al. (1991)) reports success with a power density of 3 watts/cm². The frequency refers to the frequency of vibration of the transducer. As the frequency increases, the power density must also be increased to ensure cavitation. Successful results have been documented with frequencies ranging from 9 to 800 kHz.

Other parameters that affect the destruction of microorganisms include:

1. Duration of treatment: Treatment times of 1 to 60 minutes have been used with success.
2. Volume of treatment chamber: Greater volumes dissipate ultrasonic energy and can lead to "dead zones" of cavitation.
3. Geometry of treatment chamber: The length of the container affects the transmission of energy through resonance patterns. Proximity of the sample to the transducer increases effectiveness.
4. Temperature: An increase in temperature up to 60°C improves the destruction rate.
5. Type and age of microorganism population: Tolerance increases as follows: rod bacteria, yeast, coccal bacteria and spores. Fresh bacterial cultures are easier to destroy.
6. Viscosity, pressure and pH of the liquid: Viscous liquids and hydrodynamic pressure provide greater resistance to cavitation. Variable effects of pH have been observed.

These factors were used as general guidelines for the design of the experimental equipment and protocol. Some of these factors could be optimized such as the power, frequency and duration. Other parameters were matched to the ultimate application such as the physical characteristics of the liquid.

The use of fuel restricted the temperatures that could be used for safety reasons. Since sonication elevates the temperature of the sample over time, the control of temperature throughout the sample requires specific hardware. Ambient temperatures were used for the purposes of this feasibility study.

A range of microorganisms were assessed with emphasis on the strains present in fuel. Since older cultures are more resistant to destruction by ultrasound, the cultures were allowed to develop over a minimum of one week before inoculation and treatment.

Two different approaches to ultrasonic treatment of fuel were assessed. Figure 3 illustrates one of the apparatus which consists of an ultrasonic horn **36** (associated with a controller **38**), a treatment cell **40** and peristaltic pump **42**. The horn used operates at 20 kHz, which is an optimum value for the purposes of this study. This frequency is at the low end of the ultrasonic spectrum which promotes cavitation and it is at the upper limit of the audible frequency range thus minimizing potential damage to hearing. The treatment cell **40** was specially designed and consisted of an input, an output with a valve, **44**, and an overflow. The overall volume was minimized to focus the ultrasonic energy. In particular, the volume directly under the tip was 1 cm^3 if the tip was placed 1 cm from the bottom surface.

For the static test, the outflow valve was kept closed. The fuel could be removed from the cell after the treatment was complete with a pipette or it could be recovered from the outflow when the valve was opened at the end of the treatment. The flow test was performed by continuously pumping fuel from a source reservoir **46** into the treatment cell and allowing it to flow out through the open valve **44** into a processed fuel reservoir **48** while maintaining a fixed level within the cell. The diameter of the outflow was 1/16". This maximized the surface area under the tip of the horn and ensured that fuel did not bypass the treatment. It also limited the

flow rate so that the success of the treatment could be verified before proceeding to faster rates. The flow rate with this setup was 10ml/min.

Figure 4 illustrates another apparatus used to test the process. In this test, an industrial ultrasonic cleaner **50** was used as an alternative to the ultrasonic horn flow test illustrated in Figure 3. The fuel was pumped with a pump **52** from a source reservoir **54** through a long length of tubing **56** which was immersed in the cleaner's sonicator bath **58** and into a processed fuel reservoir **60**. The cleaner had eighteen transducers **62** distributed across the bottom. The bottom surface had dimensions 18" x 12". This maximized the length of tubing immersed in the liquid and allowed longer treatment times for a given flow rate. The cleaner consisted of a 250 and 500 watt generator and operated at 40 kHz. The power and temperature could also be varied. The maximum power output at ambient temperature was about 580 watts. The cleaner was at roughly twice the frequency of the ultrasonic horn of Figure 3.

Both static and flow tests were conducted on each test apparatus. The settings for each experiment are summarized in the following table:

	Ultrasonic Horn		Ultrasonic Cleaner	
	Static Test	Flow Test	Static Test	Flow Test
Power setting	55, 175 watts	minimum successful setting from static test	100 watts	290, 580 watts
Volume	75 ml	75 ml	5 ml sample in 400 ml bath	150 ml sample in 4-6 L bath
Duration	5 min.	---	5, 10, 20 min.	---
Flow rate	---	10 ml/min	---	10 ml/min initially, increased if successful

Static Tests

Figures 5 and 6 illustrate the results of the static tests. The static test was performed to identify the approximate power level which could successfully destroy microorganisms over different treatment durations. Both the ultrasonic horn and the ultrasonic cleaner were able to eliminate the microorganism counts in most cases. It was found that bacteria and aerobic microorganisms were the most resistant.

The ultrasonic horn results suggest that the medium setting should be sufficient for the flow test but that the flow rate should be minimized. Results using the ultrasonic cleaner showed that despite the larger basin volumes, this geometry is also feasible for the disruption of microorganisms.

Flow Tests

Figures 7 and 8 illustrate the results from the flow tests. The ultrasonic horn flow test was performed at the medium (55 watts) setting with a flow rate of 10 ml/min. Samples were taken from the outflow valve after 1 and 2 minutes and from the overflow tube after 7 and 8 minutes. Both outflow ports were tested because recontamination of the treated fuel can easily occur. If one outflow port had become unsterile, useful results could still be obtained.

The results showed that the overflow tube may have been unsterile. Microbial counts were reduced from controls only in the case of aerobic bacteria when the overflow tube was used. In contrast, both the aerobic and anaerobic bacteria were reduced by at least two orders of magnitude when the outflow valve was used. The yeast and fungi were not destroyed by this process. In some cases the counts were actually increased. This can be attributed to variability

in the counts, to equipment sterility issues, or to the dispersion of colonies. The latter case may occur if the intensity or duration of the treatment is insufficient for destruction. The microorganisms would have greater access to nutrients and thus proliferate more readily after dispersion.

Disruption of Microbial Mats

In this study, contaminated marine diesel was mixed together into two large batches. One was combined with 2 L of distilled water and 20 g of NaCl. The other batch was combined with water collected from Lake Ontario. Mats were allowed to grow for more than one month with periodic inspection and agitation. The optimum conditions determined by the above tests were used to disrupt the mats. Viability of the mat microorganisms and the dispersion of the mats were assessed.

The microbial mat at the interface of diesel fuel and distilled water with salt grew to about 2 mm with up to 1 cm protruding into the water layer at certain points. The lakewater contained more particulate matter but the mat grew to about 1 mm. After more than one month of growth, the cohesiveness of the mats was assessed. The lakewater mat broke into pieces on contact but the salt water mat was extremely cohesive. The salt water mat was selected for ultrasonic processing.

The ultrasonic horn and the cleaner were used for disruption of the mats. The horn was operated at the medium setting (55 watts) in the static mode for 5 minutes. The cleaner was operated at the high setting (580 watts) with a pump speed of 30 ml/min. The volume treated for both cases was 75 ml.

All equipment was sterilized with alcohol for about 1 hour. The mats were drawn up in syringes and placed in the control container and in the ultrasonic horn processing container. The

input end of the tubing used in the ultrasonic cleaner could not be accurately held at the level of the mat during continuous pumping. Thus, the fuel used in the ultrasonic cleaner test contained much less mat material than in the ultrasonic horn test.

The fuel and water processed by the ultrasonic cleaner were extremely clean with little particulate matter at the fuel-water interface. Therefore, the dispersion of the mat could only be assessed after processing with the ultrasonic horn. The mat thickness had increased to about 6 mm and dispersed upon shaking. The water contained a lot of particulate matter. When left standing, the mat material returned to the fuel-water interface but it consisted primarily of loose particulate matter.

The viability of the microorganisms in the mat was assessed before and after processing. It was found that the ultrasonic horn had destroyed the microorganisms more completely than the ultrasonic cleaner. The laboratory assessment of this test equated <10 / ml with complete disruption.

Water Reaction Test

The water reaction test involves shaking a 100 ml graduated cylinder containing 80 ml fuel and 20 ml distilled, de-ionized water for 2 minutes (2-3 strokes/sec. using 15-25 cm strokes). After this process the cylinder is left untouched for 10 minutes. The degree of fuel/water separation at the 10 minute mark is assessed on a scale of 1 to 4.

The ultrasonic horn and the ultrasonic cleaner were used for the water reaction tests. The horn was operated at the medium setting (55 watts) in the static mode for 5 minutes. The volume treated was 100 ml. The cleaner was operated at the high setting (580) watts with a pump speed of 30 ml/min. The volume treated was 80 ml.

The untreated control fuel was pumped into the graduated cylinder through the ultrasonic cleaner tubing. This fuel failed the test with a rating of 3. The emulsion at the fuel-water interface was about 5 ml after 10 minutes of standing.

Two tests were performed with the ultrasonic horn. The first test was performed on fuel in a wet container. This arrangement passed the test with a rating of 1. A lacy film remained at the fuel-water interface and extended down 3 ml markings at its lowest point. The lacy bubble covered about ¼ of the interface area. Otherwise, both fuel and the water were extremely clear.

The second test in the ultrasonic horn was meant to demonstrate the worst case in ultrasonic processing. The container held 20 ml of water and 80 ml of fuel. The tip of the horn was placed at the fuel-water interface, just inside the fuel. During processing, an emulsion could be seen developing. After the 5 minute processing period, the fuel and water were inseparable. Thus, 80 ml of this mixture was used in the test. The water was completely opaque after standing 10 minutes and the emulsion layer was about 9 ml. This failed the water reaction test with a rating of 4.

The ultrasonic cleaner test passed with a rating of 1. Thus, it seems that ultrasonic treatment of the fuel can actually improve its quality. It is believed that this effect results as particulate matter separates out of the fuel due to the exposure to ultrasonic vibrations.

Ring Configuration

In a further embodiment of the invention, as illustrated in Figure 9, a series of piezoceramic ring transducers **66** having a power supply **68** are attached to the exterior of a fuel conduit **69**. The transducers **66** are arranged so as to direct ultrasonic energy towards the centre of the ring and, therefore, directly to the fuel flowing through the conduit. Tests of this system (with a ring having an inside surface area of 150 cm^2) showed that cavitation of the fluid in the

conduit was established at 500 watts input power. This result indicates that the ring configuration is uniquely efficient and that significant savings in power can be achieved with the ring configuration. The figure also illustrates the possible use of a turbine 70 for the creating turbulence in the fluid to be treated as well as bends, 72, in the conduit as passive sources of turbulence.

The results from this study have demonstrated that the ring configuration is highly efficient and that it is feasible to utilize this concept for a full scale treatment system for shipboard fuel. In comparison to the other embodiments discussed above, the ring configuration represents significant power and overall cost savings. It also conserves space and is more reliable due to its simplicity.

The following techniques have been proposed for the distribution of ultrasonic energy throughout the ring volume:

1. Activate entire rings with active or passive turbulence to induce mixing.
2. Alternate activation between two opposite halves of the ring.
3. Alternate activation between two pairs of opposite quadrants of the ring.
4. Alter the geometry by arranging ring segments within a larger pipe.

Figure 9 shows a design illustrating how these alternative strategies for the ring configuration might be implemented.

The first alternative implementation strategy for the ring configuration is to introduce turbulence or mixing into the fuel system. This will ensure that all of the fuel passes through the zone of highest cavitation for maximum cleaning. This would require the arrangement of one or more series of rings along the fuel flow. The mixing could be promoted either actively or passively.

Because the ultrasonic waves converge at the centre of the ring volume, optimum cavitation occurs in this region. The energy could be distributed over a greater area by activating only half of the ring at once. The ultrasonic waves can travel across the ring in one direction only, or be pulsed in opposite directions. This strategy can be further enhanced by alternating the position of the active transducer surface around the pipe for each successive ring.

The transducer ring plating has been divided into quadrants. This facilitates the activation of one pair of opposite quadrants at once, followed by the other pair of quadrants. The collision of the wave fronts will increase the efficiency of the system and compensate for the activation of only half of the transducer surface area at once.

The unique curved profile of the ring shaped transducers could be utilized in novel geometries. It may be found that optimal positioning of these transducers can be achieved by dividing the ring segments into quadrants and arranging these within or around a flow-through system. While the transducers do not constitute the flow-through section in themselves in this approach, the curved surface may serve to focus and direct the ultrasonic energy.

Although the invention has been described with reference to certain specific embodiments, various modifications thereof will be apparent to those skilled in the art without departing from the spirit and scope of the invention as outlined in the appended claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An apparatus for the ultrasonic treatment of a microbiologically contaminated liquid comprising:

a treatment chamber containing an ultrasonic vibration generating means for subjecting ultrasonic vibrations on said liquid at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction;

wherein said contaminated liquid is passed through said chamber and is subjected to said ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

2. An apparatus for the ultrasonic treatment of a microbiologically contaminated liquid comprising:

an inlet manifold adapted to receive a stream of said contaminated liquid and to distribute said liquid into at least one treatment chamber;

said chamber comprising an ultrasonic horn oriented to subject ultrasonic vibrations to said liquid at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction; and,

an outlet manifold to collect said liquid from said chamber;

wherein the liquid passing through said chamber is subjected to ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

3. An apparatus for ultrasonic treatment of a microbiologically contaminated liquid comprising:

a tank adapted to contain said liquid;

at least one ultrasonic transducer arranged to provide ultrasonic vibrations through said liquid contained in said tank at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction;

wherein the contaminated liquid is subjected to ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

4. An apparatus for ultrasonic treatment of a microbiologically contaminated liquid comprising:

a cleaning tank adapted to contain a liquid medium;

a conduit within said tank and immersed in said medium;

at least one ultrasonic transducer arranged to provide ultrasonic vibrations through the medium contained in said tank at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction;

wherein said contaminated liquid flows through said conduit and is subjected to ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

5. The apparatus of any one of claims 1 to 4 wherein the liquid is a fuel.

6. The apparatus of any one of claims 1 to 4 wherein the liquid is marine ballast water.

7. A process for neutralizing microbiological contamination of a liquid fuel mixture comprising subjecting said fuel to ultrasonic vibrations at a predetermined vibration energy level and with a predetermined frequency, intensity, and duration, whereby said ultrasonic vibrations result in cavitation within said liquid.

8. A process as defined in claim 7 wherein said treatment is conducted in a batch process.

9. A process as defined in claim 8 wherein said ultrasonic vibrations are generated by an ultrasonic horn.

10. A process as defined in claim 8 wherein said ultrasonic vibrations are generated by an array of ultrasonic horns.

11. A process as defined in claim 8 wherein said treatment is performed in a tank and said ultrasonic vibrations are generated by an ultrasonic transducer.

12. A process as defined in claim 8 wherein said treatment is performed in a tank and said ultrasonic vibrations are generated by an array of ultrasonic transducers.

13. A process as defined in claim 7 wherein said treatment is conducted in a flow through process.

14. A process as defined in claim 13 wherein said ultrasonic vibrations are generated by an ultrasonic horn.

15. A process as defined in claim 13 wherein said ultrasonic vibrations are generated by an array of ultrasonic horns.

16. A process as defined in claim 13 wherein said treatment is performed in a tank and said ultrasonic vibrations are generated by an ultrasonic transducer.

17. A process as defined in claim 13 wherein said treatment is performed in a tank and said ultrasonic vibrations are generated by an array of ultrasonic transducers.

18. A process for neutralizing microbiological contamination of ballast water from a sea vessel comprising subjecting said ballast water to ultrasonic vibrations at a predetermined vibration energy level and with a predetermined frequency, intensity, duration, whereby said ultrasonic vibrations result in cavitation within said ballast water.

19. A process as defined in any one of claims 7 to 18 wherein the frequency of the ultrasonic vibration is in the range of 9 kHz to 1 MHz.

20. A process as defined in any one of claims 7 to 18 wherein the frequency of the ultrasonic vibration is in the range of 20 kHz to 100 kHz.

21. An apparatus for the ultrasonic treatment of a microbiologically contaminated liquid comprising at least one ultrasonic ring transducer through which is contained a conduit containing said liquid, said transducer being arranged to provide ultrasonic vibrations to said liquid at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction, wherein said contaminated liquid is subjected to ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

22. The apparatus of claim 21 wherein a series of transducers are spaced along said conduit.

23. The apparatus of claim 22 further having a turbulence generating means within said conduit to cause turbulence in said liquid.

24. The apparatus of claim 23 wherein said conduit incorporates bends for causing turbulence in said liquid.

25. An apparatus for the ultrasonic treatment of a microbiologically contaminated liquid comprising:

a conduit through which flows said liquid;

a series of ultrasonic ring transducer through which said conduit passes, said transducers being arranged to provide ultrasonic vibrations to said liquid at a predetermined vibration energy level and with a predetermined frequency, intensity, duration and direction;

a turbulence generating means for causing turbulence within said liquid;

said conduit having bends along its length for causing turbulence within said liquid

wherein said contaminated liquid is subjected to ultrasonic vibrations resulting in cavitation in said liquid and the destruction of microorganisms contained therein.

26. The apparatus of any one of claims 21 to 25 wherein the liquid is a fuel.

27. The apparatus of any one of claims 21 to 25 wherein the liquid is marine ballast water.

28. A process for disrupting a mat of microorganisms comprising subjecting said mat to ultrasonic vibrations at a predetermined vibration energy level and with a predetermined frequency, intensity, duration whereby said ultrasonic vibrations disintegrate said mat.

29. A process for improving the water separation characteristics of a liquid fuel comprising subjecting said fuel to ultrasonic vibrations at a predetermined vibration energy level and with a predetermined frequency, intensity, duration.

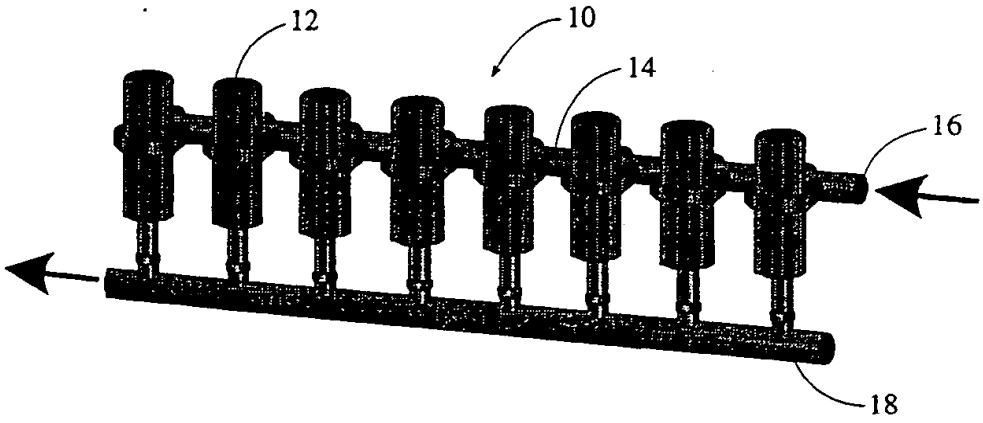

FIGURE 1

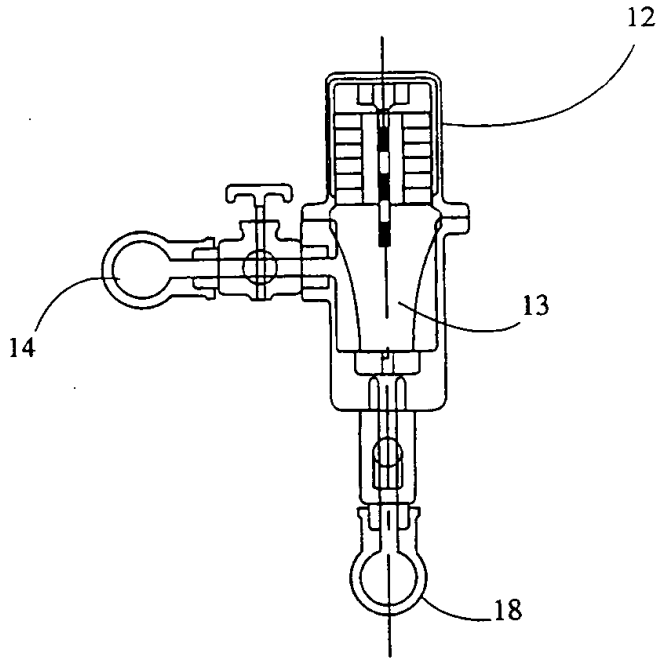

FIGURE 1A

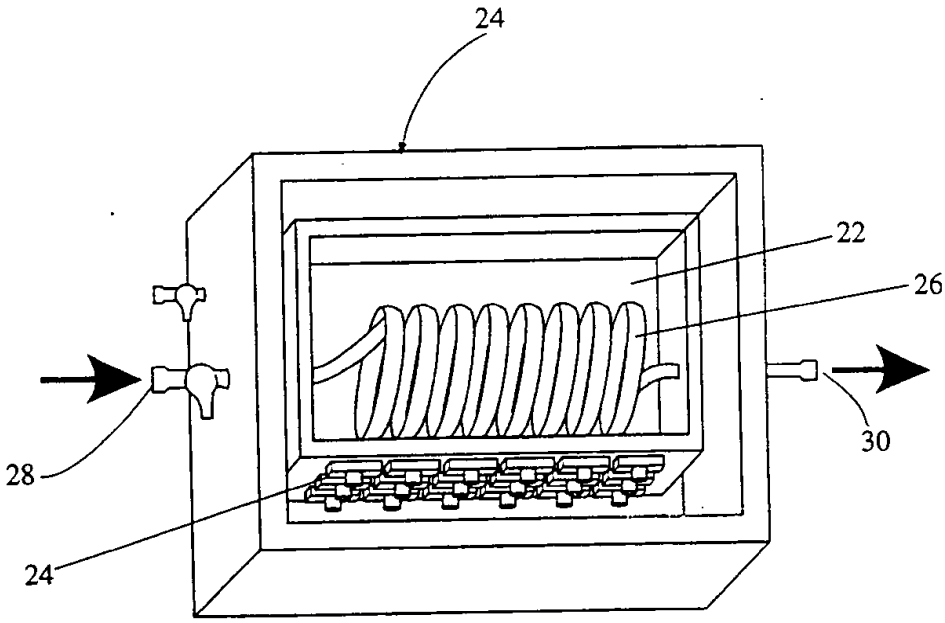

FIGURE 2

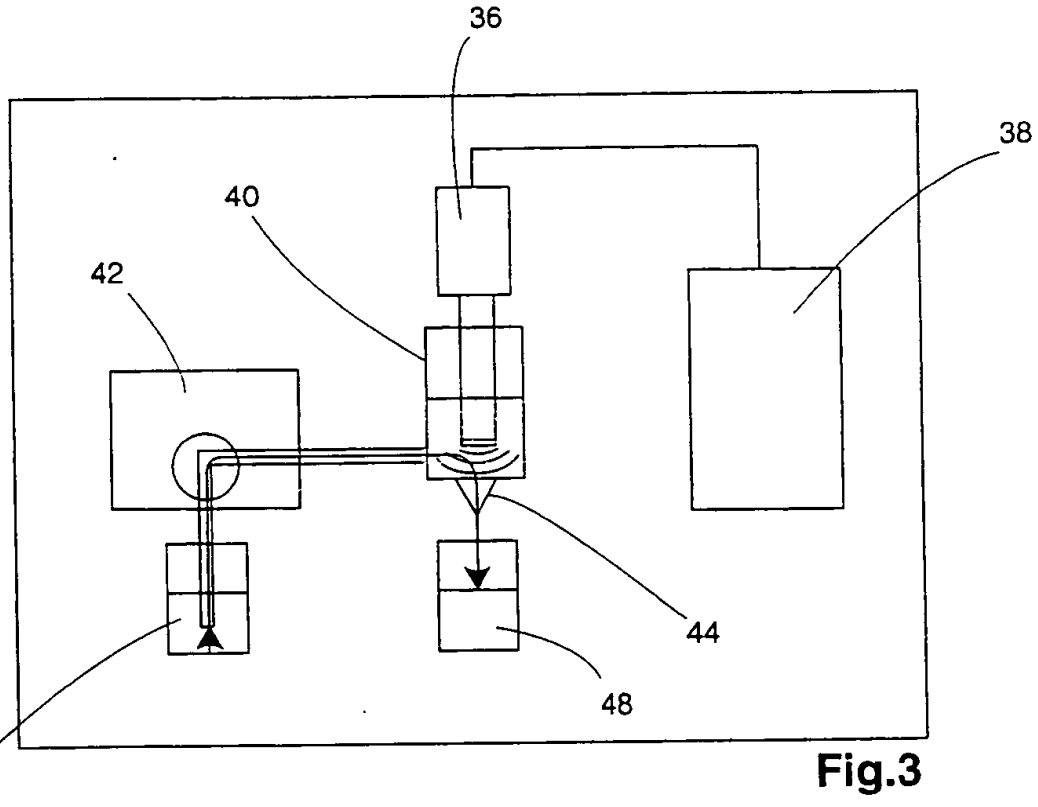

Fig.3

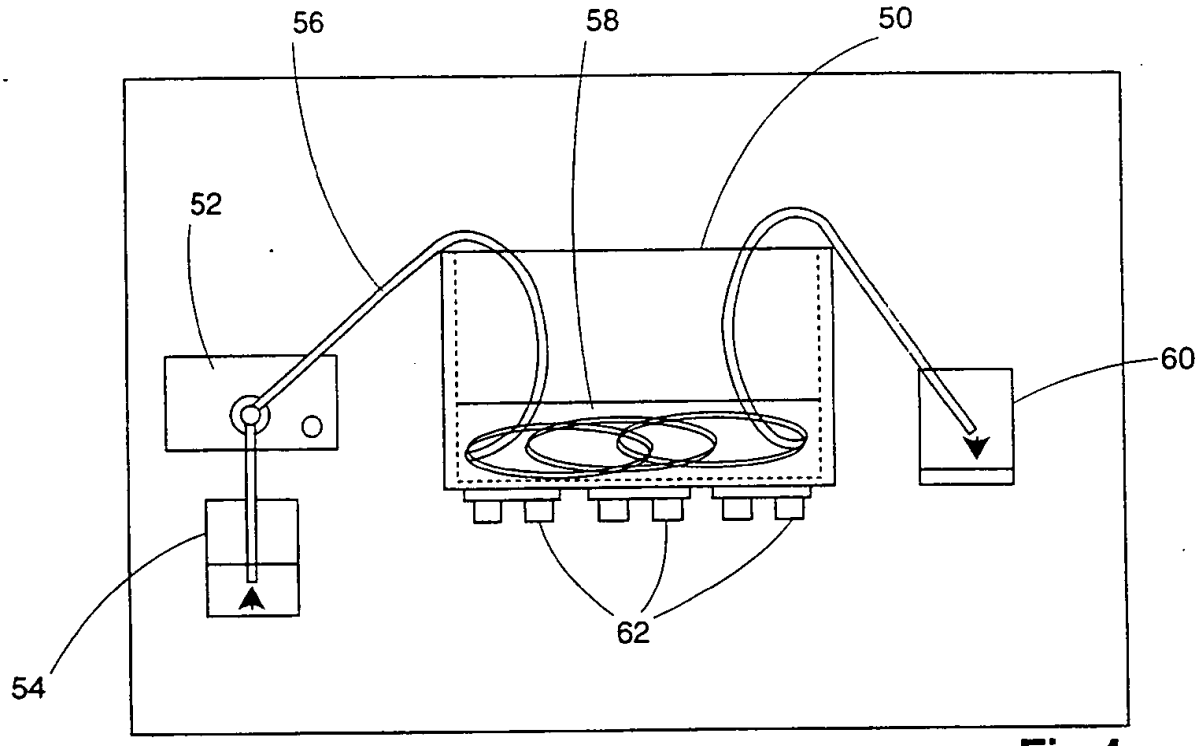

Fig.4

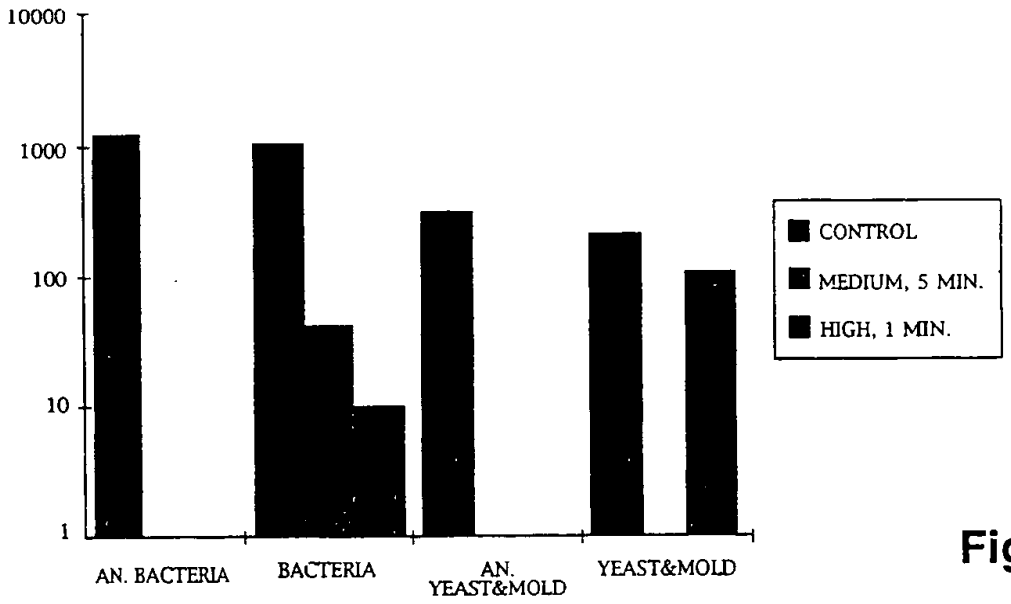
10000
1000
100
10
1
AN. BACTERIA
BACTERIA
AN. YEAST&MOLD
YEAST&MOLD
CONTROL
MEDIUM, 5 MIN.
HIGH, 1 MIN.

Fig.5

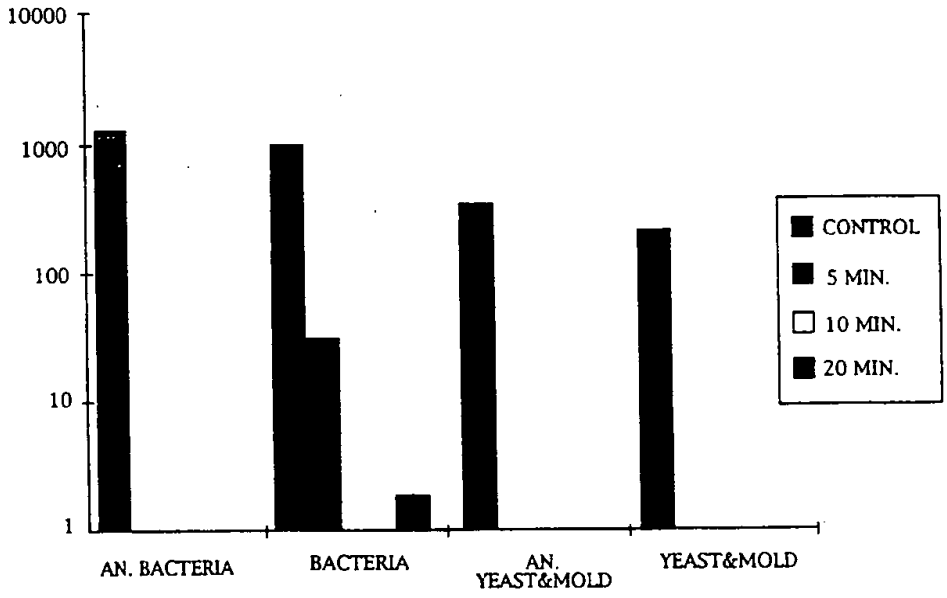
10000
1000
100
10
1
AN. BACTERIA
BACTERIA
AN. YEAST&MOLD
YEAST&MOLD
CONTROL
5 MIN.
10 MIN.
20 MIN.

Fig.6

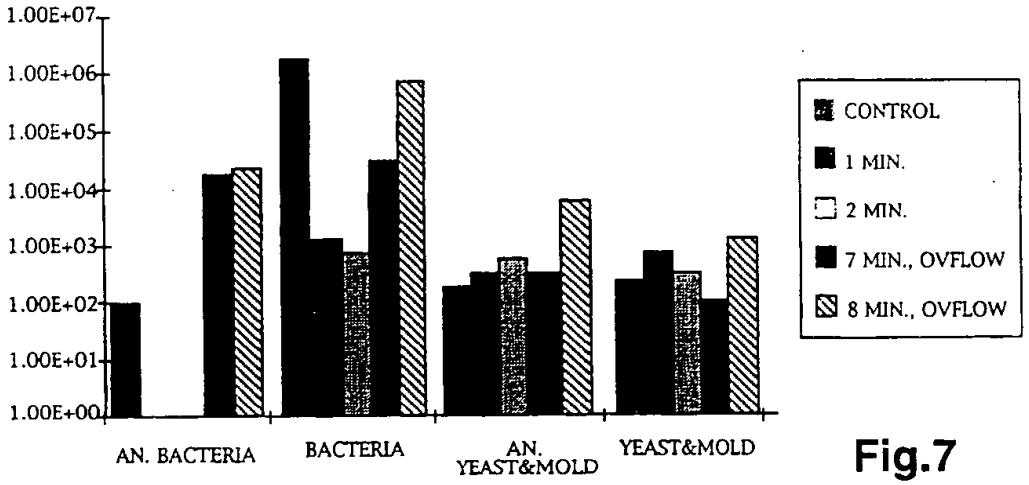
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
AN. BACTERIA
BACTERIA
AN. YEAST&MOLD
YEAST&MOLD
CONTROL
1 MIN.
2 MIN.
7 MIN., OVFLOW
8 MIN., OVFLOW

Fig.7

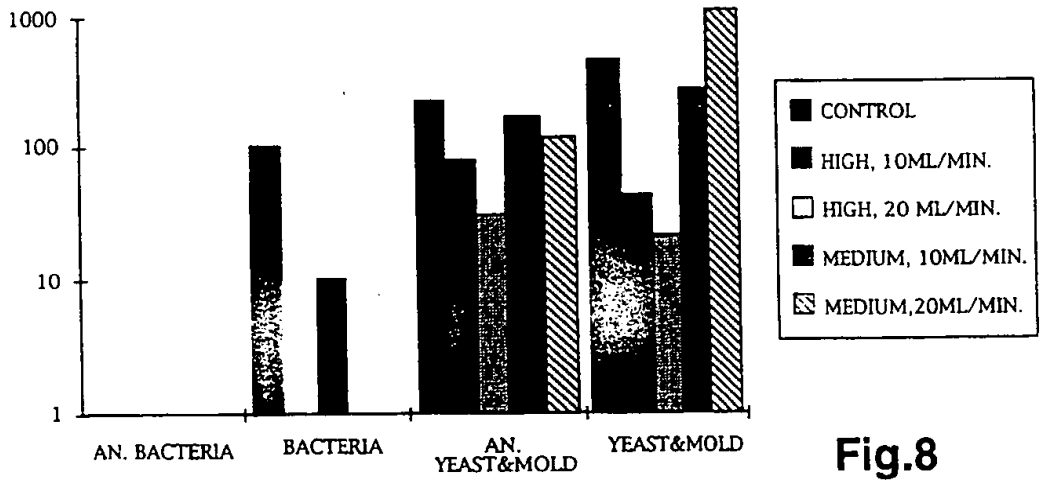
1000
100
10
1
AN. BACTERIA
BACTERIA
AN. YEAST&MOLD
YEAST&MOLD
CONTROL
HIGH, 10ML/MIN.
HIGH, 20 ML/MIN.
MEDIUM, 10ML/MIN.
MEDIUM,20ML/MIN.

Fig.8

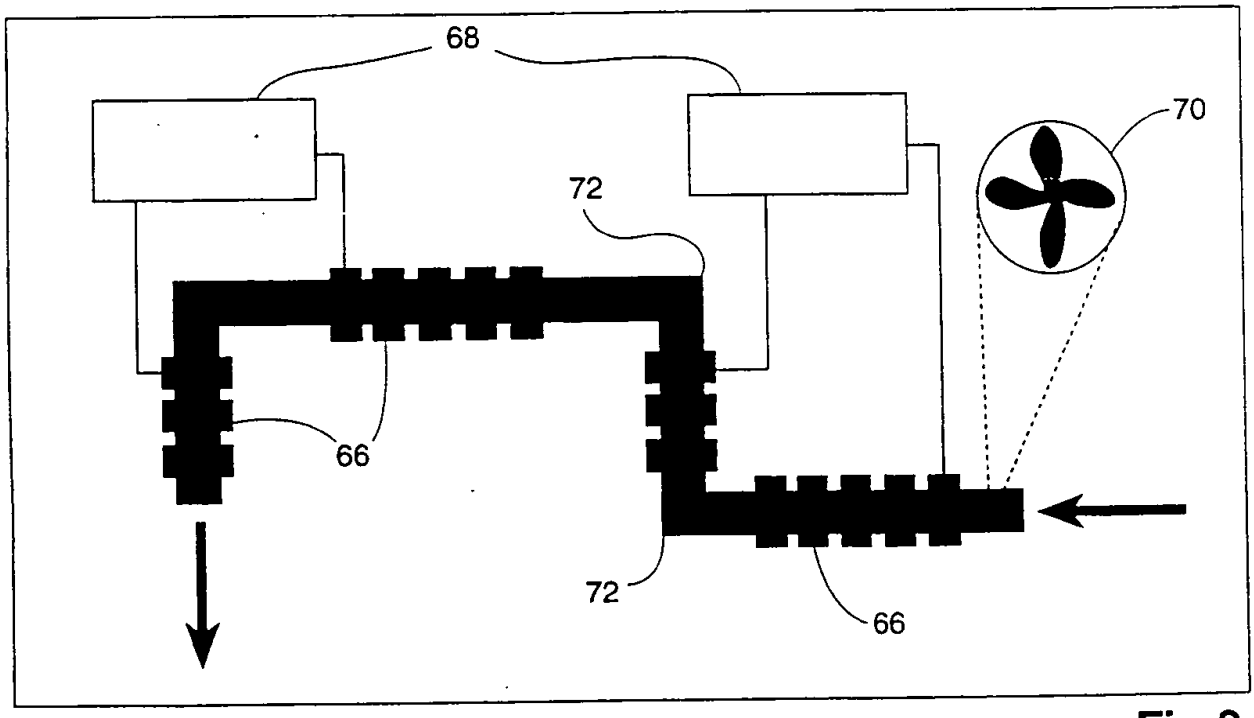

Fig.9